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Smith, T.W.; Weber, W.G.; Smith, R.E.

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HIGHWAY RESEARCH REPORT

A FIELD EVALUATION OF COMPACTION CONTROL WITH NUCLEAR GAGES

68-58

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 632697-6

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads August, 1968

FINAL REPORT

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, *Governor*

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

A FIELD EVALUATION OF

COMPACTION CONTROL

WITH NUCLEAR GAGES

TRAVIS SMITH
Principal Investigator

W. G. WEBER, D. R. HOWE
Field Investigation

R. E. SMITH, C. T. GIPSON
Analysis and Report

Assisted by:
Bobby Lister
and others

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Smith, T. W., Weber, W. G., Smith, R. E., "A Field Evaluation of Compaction Control With Nuclear Gages," State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report No. M&R 632697-6, August, 1968.

ABSTRACT: The experience gained in the use of portable nuclear gages in compaction control on eleven projects at various locations in California is reported. Both backscatter and transmission type gages of various manufacture were employed. It was found that the backscatter type gages available did not have the basic capacity to be used in general compaction control. The transmission type gage was found to be satisfactory. It was concluded that the time required and overall cost of nuclear density testing was greater than that of the previous method, but was compensated for by better coverage of the project. The general experience with safety, gage breakdowns, gage design, and test method is discussed. As a result of this research, the California Division of Highways has adopted the transmission type nuclear density test as an optionally specified method for control of compaction.

KEY WORDS: Soils, compaction control, nuclear applications, nuclear moisture-density determinations, field measurements, field testing, evaluation, testing equipment.

ACKNOWLEDGEMENTS

Appreciation is extended to all those individuals within the California Division of Highways who participated, directly and indirectly, in this research. Particular recognition is extended to the Resident Engineers on the various projects concerned.

This is a final report on work done under the HPR Work Program as Item No. F-4-3 in cooperation with the U.S. Department of Transportation, Federal Highway Administration, U.S. Bureau of Public Roads.

The opinions, findings, and conclusions expressed in this publication are those of the authors, and not necessarily those of the Bureau of Public Roads.

TABLE OF CONTENTS

TABLE OF CONTENTS

INTRODUCTION

Scope of Report

This report presents a qualitative summary, in non-technical terms, of a large scale research project investigating the technical and administrative problems in the use of nuclear soil gages in compaction control. Data reports on five of the projects on which these instruments were used have been previously prepared. They are: Materials and Research Department reports No. M&R 632697-1, through 5. These reports were prepared on projects in the following California Highway Districts respectively: 03, 05, 02, 06 and 10, references (1)through (5).

Interim data reports were not prepared for the remaining projects, as the experience seemed to be largely the same as that previously reported. The data from the first projects were reported somewhat formally for the use of this department, and the various highway districts, in evaluating the use of the nuclear soil gages in compaction control. This procedure made the information available for use before the publication of the final report. Those interested in reviewing typical field data may refer to the reports cited.

Project History

Research prior to 1965 by the Materials and Research Department of the California Division of Highways, and other agencies in the United States and elsewhere, had indicated the apparent technical feasibility of using the nuclear gages in compaction control. (6) Preliminary research by this department to determine whether they could be practically used in construction control was begun in 1964-65. At that time, a project in California Highway District 01 used a backscatter nuclear density gage instead of the sand volume method with favorable results, to control placement of embankment (7).

In 1964 a limited study was conducted in the Sacramento area by personnel from this department. Its object was to investigate the practicality of using a nuclear gage based at a central location for density testing on several projects, and to gather data on multiple testing with the device. The gage was not actually specified as the control on the projects, but was used to supply supplemental field density information to construction personnel. The results were somewhat inconclusive, but it was determined that the availability of more than one gage was essential; and that central control should be practical on projects in close proximity. (8)

Concurrently, in 1964, a cooperative research project was conducted by the California Division of Highways and the Department of Water Resources. This was a comprehensive laboratory study of some of the basic factors influencing a nuclear soil moisture or density determination. In particular, it was found that surface texture has a profound effect on a density determination made with the backscatter type nuclear gage. This type gage is one in which the source and detector tube are both housed in the body of the gage. The instrument is placed on a prepared soil surface to determine density.

The transmission type gage was also investigated in this research. In this system, either the nuclear source or the detector tube is contained in a rod which is inserted some given depth into a hole prepared in the soil. It appeared that this type gage had an accuracy comparable to the sand volume density test; and was superior to the available backscatter gages in this respect. (9)

As a result of the foregoing research it was concluded that the transmission density gage had the technical capacity to be used in compaction control. It was felt that the backscatter type gage was marginal in this regard, but might be satisfactorily used in a test method where multiple field density determinations were averaged for use in control.

Research Objectives

At this point, it was decided that applied research, on a variety of projects, was necessary to determine practical problems occurring when these gages were the specified method of compaction control. It was desired to pursue the following interrelated objectives:

1. Develop a knowledge of the frequency and effects of gage breakdowns. This could only be gained by placing instruments of different manufacture and type on a variety of projects.

2. Develop a practical test method for compaction control utilizing the nuclear gages, which could be implemented by field personnel and accepted by the contractor.

3. Evaluate the overall economics of nuclear density testing, considering the amount of test results, speed, convenience, personnel requirements, etc.; in comparison with previous methods.

4. Gain a greater experience in meeting the safety and regulatory requirements attendant with the use of nuclear gages on construction projects.

A formal proposal was made to investigate these questions under the Bureau of Public Roads research program. Specifically, it was proposed to place nuclear gages on construction projects at various locations in the state. Complete records of field test data would be maintained, as well as of instrument functioning and radiation exposure. The opinions of those involved in the on-the-job use of the instruments would be solicited. It was believed that such a program would provide not only the necessary experience to evaluate the practical operational and administrative aspects of nuclear density testing, but also technical data on field gage performance.

The research proposal received approval in late 1964, and was titled, "Evaluation of Problems in the Field use of Nuclear Moisture and Density Gages for Compaction Control."

CONCLUSIONS

1. It is practical and satisfactory to use the transmission type nuclear soil gages in compaction control. The accuracy is acceptable, being comparable to the sand volume test. A single density calibration curve may be used for all soils when employing the deeper probe positions, with no adjustment required for soil type or surface texture. The use of the gages is not objectionable to the contractors. Subsequent to this research, the California Division of Highways has adopted the transmission type nuclear density test and a statistical type test method as an optional method of control of embankment construction.

2. Surface preparation and hole drilling are still problems with the transmission gage. However, the time taken to prepare a site for a transmission density test is usually no greater than that required to insure a smooth soil surface for the backscatter gage. It is believed the necessary site preparation might be reduced by minimizing the soil contact area on the bottom of the transmission type gage.

3. The commercially available portable backscatter gages used on this research were not considered suitable for compaction control.

4. Field calibration by correlation with in-place densities determined by the sand volume method tends to be unsatisfactory, and should be discouraged. When correlating the nuclear gages with bulk densities of soils compacted in large molds, it is difficult to get a satisfactory range of densities. Permanent density and moisture standards should be maintained for the calibration and checking of the units.

5. The use of the nuclear method in compaction control results in a greater total expense than the previous method. However, it is concluded that better coverage results for the time and money spent. Administrative work is increased with the nuclear method, but is not found to be overly burdensome. This has been further reduced subsequent to the period of research due to the very satisfactory record of experience with regard to health safety.

6. There appears to be little fear or apprehension, with regard to the use of the instruments containing nuclear isotopes, on the part of state forces, the public, or the contractor's personnel. There was no record of radiation exposure or any mishap creating an unusual hazard. However, a continuing positive program of training and inspection is required to maintain good practices.

7. To prevent lengthy out-of-service periods when the nuclear gages need repair; in-house capability for trouble shooting and servicing of these units should be attained. With this, and the trend toward transistorized modular components, gage down-time should be minimized in the future. However, back-up gages will still be necessary. Based on the experience gained in this research, it is estimated that one back-up gage for three or four instruments in field use is required. It is probable this ratio can be reduced in the future.

8. The internal batteries used in the nuclear gages were not dependable because of their short life. It was generally found to be better practice to use the vehicle battery as a power source.

9. It is satisfactory under certain conditions, to use as a compaction control standard, the average of several test maximum densities which have been previously determined and which are considered representative of a particular soil. This is permissible when the resulting average test maximum density is used in conjunction with the mean of several field density tests in an area. A continuing testing program to detect changes in the soils characteristics is also required.

10. It is recommended that future gage specifications provide for: elimination of the internal battery, full plug-in circuit board construction, and fabrication such that the source and shielding assembly can be separated intact from the gage electronics.

PREPARATION AND PROCEDURE

Project Selection

Eleven projects in ten of the California Highway Districts on which the nuclear density gages would be used were selected on the basis of availability, location, variety of soils, and nature of construction. On these projects, it was specified in the contract Special Provisions that the nuclear equipment was to be used to determine in-place densities for compaction control in place of the sand volume test. The use of the nuclear gages was to be under the direct control of the resident engineer.

In some cases, the gages were also used for control testing on minor adjacent projects.

Gage Procurement and Assignment

In early 1965, ten nuclear soil gages were purchased from four manufacturers. The disposition and use of these units are shown in Table No. 1. The soil gages were purchased for the program from funds other than those under the research authorization. A rental rate was established for this equipment, and charged against the project on which it was used. All maintenance and repair of the devices were paid for from this fund. A record of down-time and its cause was kept by this department.

Six of the ten gages purchased were primarily designed as transmission type devices. However, these could also be used in the backscatter mode. Three of these six gages were built by the Troxler Corporation of Raleigh, North Carolina, with the nuclear source in the extendable probe. The other three were Hidrodensimeters, manufactured by Viatec, of South Africa. In the Hidrodensimeter, the source is in the body of the instrument and the detector tube is within the probe.

The other four gages purchased for the program were of the backscatter type. Two of these were obtained from the Nuclear Chicago Corporation of Des Plaines, Illinois. The Nuclear Materials and Equipment Corporation, Apollo, Pennsylvania, supplied the remaining two gages which have the trade-name "Numec."

It is seen in Table No. 1 that project #4 was supplied with gages obtained under a subsequent purchase. The first, a Nuclear Chicago, was essentially a backscatter gage modified by the manufacturer to comply with the California specifications in effect at the time. It was replaced with a Troxler as noted, also obtained at a later date.

Project No. 8 was provided with backscatter gages transferred from projects #9 and #11. The replacement gage for project #9 was an older unit which was owned by the California Division of Highways. The replacement gage for project#11 was transferred from project #7 after its completion.

One of the ten gages obtained in the original purchase, a Hidrodensimeter, was not assigned to a project. This unit was retained in the Sacramento Materials Laboratory to be used in other research; and to serve as a back-up gage.

Training

Usually the resident engineer and two of his technicians were trained in the use of the nuclear equipment. Also, one person from the district headquarters responsible for auditing the job progress received instruction. This training program consisted of three days of classroom work covering the basic concepts of nuclear physics, health safety, and the application of the test method. Two days of practical experience in operating the gages completed the course. For those in the northern portion of the state, the classes were conducted in Sacramento. Los Angeles was the training site for the southern highway districts.

At the start of compaction operations on each project an experienced technician from this department spent at least one week on the project. This was to complete the training of district operators and insure that the equipment was functioning properly. These technicians also made an average of three visits to each project during its active phase. The visits were made to aid the district personnel with any difficulties that developed in the use of the gages, to check the operation of the gages, to check the health safety procedures; and to note any apparent weaknesses in the training program.

Health Safety

The gage operators were given a physical examination by physicians certified in nuclear health. Each operator was required to have this examination at the beginning of the study, and each year thereafter until the project was finished. Also, those operating the gages were required to wear film badges, and a pen-sized monitoring device called a dosimeter. All records of medical examinations, radiation exposure, and surveys of radiation levels of gages and storage areas were maintained at the Materials and Research Department.[1] The costs of keeping these records were borne by the research.[1]

Tentative Test Method

The test method written for the early research with a nuclear gage in California Highway District 01, (Calif. T-231-A,) was based on the substitution of a nuclear density determination at a single site for a sand volume test. However, experience gained in the planning stages of this project indicated that the taking of multiple tests with the nuclear gage was desirable. The project was actually controlled, therefore, on the basis of statistical sampling of an area, although this was not detailed in that test method.

Tentative test method Calif. T-231-B, as written for this research project, incorporated the experience gained in District 01. Herein, the sample average and distribution are used to determine if the compaction requirements are met by the contractor. A group of 4 to 6 nuclear density tests are taken in an area, and the average density is required to meet the relative compaction specification. This is in accordance with test method Calif. 216. Also two thirds of the individual field tests in an area were required to be above the specified relative compaction density.

The soil for the test maximum density determination was gathered at the location of the field test having the density just below the average of the area. If a soil type was demonstrated to be constant by sufficient laboratory test maximum density determinations, it was permitted to use the average or "established" control density; with periodic checking of the test maximum density.

The nuclear test method was revised again in December, 1966, (Calif. #231-C,) based on the results of this research. The principal modification was concerned with the gathering of the soil sample to be used in the determination of the laboratory test maximum density. This version of the test method directs that the soil taken for this purpose be a composite sample of material from each nuclear density test site.

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1 The required frequency of medical examinations has since been lengthened to two year periods. The use of dosimeters has been made optional.

Data Collection

A copy of all nuclear compaction test data was forwarded to this department from the various projects. This data was tabulated and analyzed to evaluate the performance of the equipment and test method.

Project Conference, Resident Engineer's Evaluation

When the study was at about the halfway point a conference was held to review and discuss the use of the nuclear soil gages on the various projects. Some minor changes in the tentative test method were discussed and were later incorporated in the revision of the test method, No. Calif. 231-C, mentioned earlier.

At the finish of each project, the Resident Engineer was requested to submit to this department his candid comments on the use of the nuclear equipment (and test method) on his job. These have been of great value in the preparation of this report.

FIELD USE AND EVALUATION OF PORTABLE NUCLEAR SOIL GAGES

Backscatter Type Density Gages

The backscatter method of testing soil density was used on six jobs. One of the primary conclusions reached in this research was that this method of density determination with commercially available portable gages was not satisfactory for use in general compaction control. This is probably caused by the shallow depth of reading of this type gage. (9). The shallowly penetrating radiation has a low probability of being moderated by soil density; tending to make the backscatter gages basically less sensitive to changes in soil density than are the transmission gages. This same factor also causes them to be much more affected by variations in soil surface texture and seating.

The effects of the surface variations between soils on the backscatter density test can be partially compensated for by adjusting or normalizing the calibration curve. However, this results in excessive calibration problems when the gages are to be used on a project having a variety of soils. On two of the six projects using the backscatter gages, the operators felt it necessary to establish five separate density curves for the various materials used in embankment, structure backfill, and roadway base. On three other projects, the operators used a separate calibration for embankment and structure backfill materials. Only one project of the six found a single calibration curve to be sufficient. A study of the data from those projects using multiple calibration curves indicates that the scatter of points on some of the individual curves was such that a correlation could not be established with a satisfactory degree of confidence.

It was determined that the backscatter gages, when used in construction control on these six projects, had an average standard error of estimate of approximately six pounds per cubic foot with respect to calibration with the sand volume test. This is in spite of the fact that the operators were using individual calibration curves established for the various soils. The indicated accuracy was not considered to be acceptable, even when employed in a test method based on a multiple sampling concept.

A principal complaint concerning the backscatter gages was the difficulty and uncertainty in seating. It turned out that as much or more time is required to prepare a suitable surface for the backscatter gage, as is required to prepare a hole for the transmission type test. These seating difficulties with the backscatter gages created another source of uncertainty concerning the density determinations.

It may be concluded that the backscatter gages, as used in this research, may be usefully employed as comparative instruments on large production runs of a single source, tightly controlled product having a smooth surface (i.e., subbase, base, etc.). They do not have the capacity to be used in a compaction control method based on absolute density values.

Transmission Type Density Gages

In contrast, soil density determination with the transmission type gage, in this field study, seemed to be much less affected by such extraneous factors as seating and surface texture. This is in agreement with the previous laboratory research performed by the department. (9) All five projects on which the transmission type test was used in compaction control were able to use single calibration curves. These curves were checked by comparison with the sand volume in-place density test, or large mold soil densities. The standard error of estimate between the nuclear density and sand volume density on these projects was two to three pounds per cubic foot.

On some jobs where the material was so rocky that the sand volume test could not be made, material was compacted in a large mold on which the transmission gage could be directly placed. A comparable correlation was experienced. In fact, on one project where the gage supplied did not have a factory calibration curve, soil compacted in a large mold formed the basis for determining the field calibration curve. It should be pointed out that the material, on these five projects using the transmission type density test, varied from a fine sand to a rocky clay.

Site preparation, though still a time consuming factor with the transmission type density determination, is not considered to be a serious problem. Common to any method of in-place density determination is the removal of disturbed surface material, either with hand or motor driven equipment. The site is leveled with a hand scraper, shovel, or other apparatus which will produce a plane surface satisfactory for seating the nuclear instrument.

A hole slightly larger in diameter than the transmission rod is then drilled or driven into the ground. A base plate with an attached pin guide is used to insure that the hole is perpendicular to the surface of the test site. In fine-grained material a steel pin can be driven into the soil with a hammer to form the hole. Where the soil contains rock fractions, the hole is drilled with an electric rotary impact hammer equipped with a carbide-tipped masonry bit. This requires a portable generator to supply power for the electric hammer.

The common transmission depths were six and ten inches, but one of the projects with rocky soil used 6, 8, 10, and 12-inch depths depending on the depth of hole the operator was able to obtain. One project, (of the 5 using the transmission test to control embankment construction) used the backscatter system in their instrument to test the structural section material, while two others used a four-inch transmission depth. The remaining two used 6, 8, or 10-inch transmission depths to test the structural section.

In summary, it was concluded that the transmission density determinations, (at probe depths of 10 inches or over) had an accuracy comparable to the sand volume test. Also, that in the same amount of time, more testing could be done with the transmission gage than with the sand volume test, in spite of the necessity for drilling the hole for the transmission rod. The transmission type nuclear density test has been adopted as an optional method of compaction control by the California Division of Highways. The acceptance of the method is based largely on the experience gained in this large scale field study of the use of the gages.

Moisture Testing

Regardless of the type of density gage assigned to a project, moisture determinations are made in the backscatter manner; that is, both the neutron source and the detector are housed within the gage body. However, it is important to realize that the phenomenon upon which the nuclear moisture test depends, differs fundamentally from that of the backscatter density test. As a consequence, the previous discussion concerning the backscatter type of density test is not applicable to the nuclear soil moisture determinations, despite the overt similarity in the testing. Those interested may refer to reference (9) for a brief discussion of the technical aspects of nuclear moisture testing.

On two of the projects using the backscatter density test, nuclear moistures were taken at the site of each density determination. Compaction control on these two jobs was conducted on a dry density basis. Another backscatter project began construction using dry densities in compaction control, but changed to the wet density method after experiencing considerable difficulty with the moisture determinations by the nuclear instrument. The remaining three of the six projects using the backscatter type test employed the wet density method from the beginning.

When it was required to make moisture determinations, five of the six backscatter projects used a single calibration curve. One of these used two moisture calibration curves.

Of the five projects using the transmission type density test, two employed the wet density method of compaction control. Soil moistures were only determined when it was necessary to make a correction to the test maximum density for oversize material. In accordance with the test method in effect at the time, this correction was made on the dry weight basis. Of these two; one project used the factory moisture calibration curve, and one did not use the moisture mode at all because of poor correlation with oven dry moistures.

The remaining three projects of the five used the transmission type nuclear test on the dry density basis. Two of these employed the manufacturers moisture calibration curve. On the remaining job, the operator felt it necessary to plot six separate moisture curves for material from different sites.

In summary, on many of the projects, the bulk of the testing was conducted on the wet density basis. It is therefore felt that the experience which was gained was not conclusive with respect to determining soil moisture with the nuclear instruments. Data were generally erratic on some jobs. It was also indicated that a considerable variation in performance existed between gages of various manufacture.

Subsequent experience has shown that the moisture content of a soil as determined by the oven-dry method, and by the nuclear method, are apt to differ. The oven-dry moisture is the equilibrium moisture established at a particular drying temperature. The nuclear soil moisture tends to be proportional to total soil water; which may include bound water, hydrates, and the hydroxyls. These are not all driven off at the normal drying temperatures. This topic is being given further study.

Calibration

As indicated in the previous discussion, calibration of the soil gages is a continuing problem. It was found that field calibration by correlation with in-place sand volume densities was unsatisfactory. This is due to the normal variability of the two density test methods, and lack of a sufficient range of field densities. Also, there is an inherent inflexibility and laboriousness in such a method, especially when recalibration may be required for any reason. This may occur when the unit is repaired, a major gage component replaced, or when it is desired to use a substitute instrument on the project. The same factor tends to discourage routine checking of gage performance.

The alternate procedure of using soil compacted in a large mold is subject to some question concerning the methods used to determine bulk density, the probable non-uniformity of material, and non-permanence. Also, a satisfactory range of densities is difficult to establish.

As a result of this research, it was concluded that it is necessary to establish a set of master reference calibration standards for both density and moisture. From these master standards, reference standards could be fabricated which would then be made available to the California Highway Districts. It is anticipated that, in the future, all California Highway Districts using the nuclear soil gages will have one or more sets of reference standards for the calibration and checking of their nuclear moisture and density gages.

Maintenance

Equipment breakdowns put some gages out of operation for as much as 23 percent of the contract working time. This was not considered to be due to rough handling or abuse, but the consequences of normal on-the-job operations and transportation over rough grades. Broken cables and dead instrument batteries seemed to be the most frequent complaint. The lack of replacement parts and easily available service was a contributing factor in the extended down periods experienced. This record was heavily drawn upon when revising the California Specifications for nuclear soil gages. (10)

It is believed that frequency and duration of breakdowns in the future will decrease with gage improvements and added experience. However, it was found impractical to depend entirely on outside facilities for gage repair. Currently California Division of Highways personnel who perform radio maintenance are being trained in the trouble shooting and minor repair of the electronic portion of these devices. The experience gained in this research also indicated the desirability of plug-in modularized or circuit board construction of the major electronic circuits in the gages.

Still, the presence of a backup gage available within a reasonable time is a necessity. It is estimated, on the basis of this research and subsequent experience, that a backup gage is required for every three or four gages being used in construction control.

It was generally found that making special provisions in the transporting vehicle for securing the instruments, and cushioning them from shock, helped minimize gage breakdowns.

Comments on Gage Design

One type of transmission gage had the nuclear source placed in the extendable rod; the detector tube being housed in the instrument body. On occasion this rod would stick in the exposed position due to the presence of dirt between the rod and guide. This created a potential hazard, and consequently, some apprehension by the users of this particular equipment. Another disadvantage of this design is the fact that the tip of the rod must be exposed to guide it into the hole prepared in the ground. Although a minor problem, it is concluded that the more desirable design from the standpoint of operator psychology is to place the source in the body of the instrument, and the detector tube in the extendable probe. All transmission gages purchased subsequently by the California Division of Highways have been designed in this manner. However, there may be technical advantages in placing the source in the ground, which could make it desirable at some future time to change this specification.

The extendable rod containing the detector tube on the transmission gage from one manufacturer was fabricated of soft aluminum tubing. This made the rod especially susceptible to sticking. The manufacturer later replaced the aluminum rod with one of stainless steel, which alleviated much of the problem.

With some gages, a great deal of difficulty was experienced with broken cables, particularly at the connectors. This has subsequently been greatly improved by the use of superior cable material, and by providing stress relief type connectors.

Another problem with several of the gages used in this research project was the inadequacy of the internal batteries supplied. These would not maintain charge long enough for dependable field operation. The most satisfactory procedure seemed to be to use the battery in the carrier vehicle as the power source. A significant portion of the internal circuitry of the presently designed gages is for the purpose of either charging the internal battery, or voltage regulation of power from this source. There is also a basic disadvantage to the designing of electronic circuitry to operate on the power produced by these small batteries. With a large source of power, the designer only uses a portion of that available; which makes the design and selection of components much less critical. Therefore, consideration is being given to eliminating the internal power sources in the specifications for future nuclear soil gages to be purchased by the California Division of Highways.

Those gages with replaceable circuit board construction were generally easier to repair, enabling a quick return to service. Easily accessible test points for the major sub-circuits (or circuit boards) are considered to be a requisite on the basis of this experience.

It is also considered to advantageous if the nuclear source and shielding assembly could be separated intact from the electronic portion of the instruments. Those persons engaged in their repair would then not be required to be concerned with the safety and regulatory requirements associated with the use of nuclear isotopes.

It is also suspected that the bottom surface contour of the transmission gage could be modified to minimize the required soil contact area. If practical, this would lessen the site preparation requirements.

Contractor Acceptance

In general, the use of the nuclear gages in compaction control was well received by the contractors. Most of them seemed to feel that they received a quicker answer as to the acceptance or rejection of their product. A study of the data indicates that approximately the same percentage of failing tests were recorded when using the nuclear method as in our previous experience. It is therefore concluded that the favorable reception to the use of these instruments was because of greater satisfaction, rather than a greater percentage of passing tests.

There were some understandable reservations on the part of the contractor if the nuclear gage breakdowns caused delay to his operation. Also, where gage calibration appeared uncertain, there was a natural tendency for the contractor to question failing tests. However, none of the contractors who had compaction controlled on their projects by nuclear density testing felt strongly that a return to the previous method was desirable.

Relative Economy of Nuclear Compaction Control

It was generally felt that the time spent in nuclear density testing equaled or exceeded that for the previous methods. But, because of the multiple testing, a much better picture was gained of the density of the area being tested. In addition, when it was possible to compute relative compaction using a test maximum density based on previous testing of the soil, the results were immediately available.

With regard to the last point, it has been commented that the same thing could have been done with the sand volume test if it had been permitted in the test method. This is not found to be valid. In a similar material, it is permissible to compare a mean field density based on several tests in an area, with the average of several test maximum densities which have been previously determined. This cannot be done rationally with a single sand volume test, or for that matter, a single nuclear density test. It is obvious that, with the sand volume apparatus, it would be difficult or impossible to take the multiple field tests required within the time usually available for compaction control testing.

While more time in the field was usually required per acceptance test; some laboratory time was saved when the nature of the material permitted the use of an average or "common" test maximum density. A saving to the contractor, even though minor, is the fact that it is not necessary to stop the heavy construction equipment when taking the nuclear density test, as is required for the sand volume density determination.

It is noted that those persons assigned as nuclear gage operators must be capable of understanding and applying the statistical sampling concepts introduced by this method of compaction control. The operators are required to exhibit some-what more sophistication in making an appropriate interpretation of test data, than was necessary in the previous method. The operator must be sensitive to the performance of the gage and its components, and provide proper care and maintenance. It is required that they understand and practice the measures necessary to maintain the legal and practical requisites of nuclear health safety. Consequently, the selection of capable persons for assignment as operators is somewhat critical.

In summary, it is found that in an economic comparison of the use of nuclear soil gages versus the previous method; the nuclear test method requires a higher expenditure. This is caused by the greater training of the personnel required, expense of gages and accessory equipment, their maintenance, and storage facilities. However, this is believed to be offset by the general flexibility of the method, and superior coverage of the project.

ADMINISTRATIVE ASPECTS OF NUCLEAR GAGE USE

Test Method

As has been commented upon, the current nuclear compaction control Test Method Calif. No. T 231-C, permits the use of an average or "common" test maximum density as the compaction control standard. This is used only after a substantial number of laboratory tests have been run, and only as long as the given material is shown by periodic testing to remain similar. It does therefore require a continuing testing program to detect changes in mean test maximum density, and range. Adjustments should be made as required. The present version of the test method is not specific on these procedures. This has resulted in some inconsistencies and non-uniformity in its application.

It is sometimes argued that soils vary too much to use such a standard in compaction control. However, it can be shown that, in a given soil, the laboratory and field densities are approximately normally distributed. This means that if a group of test maximum densities may be considered to be a representative sampling of that property for a particular soil; it is rational and practical to use the average of the group as a control standard to judge the acceptability of the mean density of a field test area.

The test method is somewhat awkward when it is required to make a correction to the test maximum density for oversized material. At present it is necessary to convert both field and laboratory densities to a dry density basis to make this adjustment. This requires the determination of field moistures concurrently with density testing. It is thought that it may be entirely practical to establish a wet-weight test maximum density which includes a correction for oversized material. Also, at this time there is no relationship drawn between the range of test maximum densities and the range of field densities. These items are undergoing study and it is probable that modifications to the nuclear test method will be in order as experience is accumulated.

It is concluded that the statistical approach to the determination of control density, as well as field density, is desirable. This should result in greater economy, and more consistent testing. Of considerable importance is the fact that it permits giving immediate decisions to the contractor without losing control.

Conformance with Regulatory Requirements

There were no difficulties encountered in meeting the health safety and regulatory requirements attendant with the use of the nuclear soil gages. A body of experience was built up from which it can be shown that the danger involved in using these instruments is minimal when proper precautions are taken. It is now known that the original schedule for exchanging film badges, for example, can be lengthened. Also, due greatly to the experience gained in this research, it has been possible to minimize the paperwork associated with keeping personnel exposure records. This has been accomplished through the cooperation of the California Division of Highways, Division of Industrial Safety, and Bureau of Radiological Health.[1]

No over-exposures to radiation were experienced on any of the projects. Nor were any of the gages involved in accidents which might have engendered loss of the nuclear source. It was found that the nuclear gages were accepted by both the contractor's personnel and state forces, and not regarded as unusual hazards.

Providing storage and transportation facilities which met the safety requirements for these instruments did not seem to be a problem on any of these projects.

Training

The general training program as originally outlined for this research has been found to be satisfactory. Those operators attending the classes seemed to be provided with the necessary information and understanding to effectively perform their duties. Some follow-up assistance or advice to the operators is usually required of course.

It is concluded that approximately three days of classroom instruction in: basic physics of nuclear radiation, health safety, radiation monitoring, and the regulatory requirements, are essential. While the theory of nuclear radiation now receives somewhat less emphasis than at first; a theoretical insight is considered to be important in the training of gage operators. A formal test is given those receiving the training and is found to be a positive incentive.

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[1]See footnote, page 6.

In addition, one to two days of instruction in the operation of the gages and interpretation of the test method is given. The operators are then given the opportunity to practice and become familiar with the equipment under project conditions.

While the original training programs were presented by the Materials and Research Department in Sacramento and Los Angeles, they are now given by the individual California Highway Districts where the nuclear method of compaction control is employed.

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TABLE NO. 1.

USE	PROJECT	DIST.	PROJECT LOCATION	GAGE MANUFACTURER	TYPE	PERIOD OF USE	*	REMARKS
TRANSMISSION TESTING METHOD	1	01	PEPPERWOOD	HIDRODENSIMETER	T,B	6-65 / 11-67	✓	
	2	02	O'BRIEN	TROXLER	T,B	4-65 / 11-66	✓	
	3	04	PLEASANTON	TROXLER	T,B	5-65 / 7-67	✓	
	4	08	NEWBERRY	NUCLEAR CHICAGO	T,B	11-66 / 5-67		NUMEROUS BREAKDOWNS IN TRANSMISSION MODE.
				TROXLER	T,B	5-67 / 6-68		
	5	10	PATTERSON	TROXLER	T,B	8-65 / 9-66	✓	
BACKSCATTER TESTING METHOD	6	03	NO. SACRAMENTO	HIDRODENSIMETER	T,B	8-65 / 5-66	✓	
	7	05	TRES PINOS	NUCLEAR CHICAGO	B	8-65 / 4-66	✓	
	8		LAS CRUCES	NUMEC(S)	B	4-66 / 6-67		GAGES TRANSFERRED FROM PROJECTS 9 & 11.
	9	06	FIREBAUGH	NUMEC	B	4-65 / 4-66	✓	NUMEROUS BREAKDOWNS
				NUCLEAR CHICAGO	B	4-66 / 10-66		OLDER GAGE PREVIOUSLY OWNED BY CALIF. DIVISION OF HIGHWAYS.
	10	07	GORMAN, CASTAIC	NUCLEAR CHICAGO	B	5-65 / 8-67	✓	
	11	11	SAN DIEGO	NUMEC	B	5-65 / 5-68	✓	NUMEROUS BREAKDOWNS.
				NUCLEAR CHICAGO	B	5-66 / 7-67		TRANSFERRED FROM PROJECT NO. 7.
			SACRAMENTO	HIDRODENSIMETER	T,B		✓	USED IN LAB. RESEARCH AND AS BACK-UP GAGE.

* - THOSE CHECKED (✓) ARE THE TEN UNITS ORIGINALLY OBTAINED FOR RESEARCH.
T,B - CAN BE USED IN TRANSMISSION OR BACKSCATTER.
B - BACKSCATTER ONLY.